Is there a size-dependency in the predator-prey interaction of *Asterias rubens* and *Mytilus edulis*?

Julia Schubert; juliachristinaschubert@gmail.com
Tina Aschenbach; tina.aschenbach@web.de

Abstract
This study examines the complex structure of prey and predator interactions, which are regulated by a variety of factors. Here, we are focusing on the prey size preference of the starfish *Asterias rubens* and its prey, the bivalve *Mytilus edulis* and its dependency on the size of the predator. Both species co-occur in the Wadden Sea of Sylt, Germany, where our experiment took place. In the course of this study we found that individuals of *Asterias rubens* favor mid-sized individuals of Mytilus edulis independently of their own size. Furthermore, our study revealed that medium-sized sea stars show the highest amount of activity in general.

Introduction

The starfish *Asteria rubens*, an echinoderm, and the mussel *Mytilus edulis*, a bivalve, form a complex prey-predator relation in the Wadden Sea of Sylt (German Bight, North Sea) where *Mytilus edulis* populations can form extensive beds (Saier, 2001). *Asteria rubens*, as many starfish, feeds by opening the mussels‘ valves using its tube feet to attach and apply force on the mussel. When the two valves sufficiently open, *Asteria rubens* inserts its everted stomach into the mussel to digest its soft tissue with the help of digestive enzymes (Lewis, 2000). *Mytilus edulis* is the preferred prey of *Asterias rubens*. The mussels occur from the intertidal down to the subtidal zone, where they attach to hard substrate such as rocks with the help of thread-like structures, called byssal threads (Saier, 2001).

The aim of our study is to investigate whether a size-dependency in the predator-prey interaction of *Asterias rubens* and *Mytilus edulis* exists. Hence we are testing three hypotheses:

Firstly, individuals of *Asterias rubens* select their prey according to their size: Large starfish attack large mussels, medium starfish attack mid-size mussels and small starfish attack small mussels. Anger et. al (1977) gave evidence that small and large starfish select their prey in different manners. Additionally, Norberg & Tedengren (1995) showed, that starfish are highly adaptive to a change in environment and prey, being able to switch their attack strategy.

Secondly, individuals of *Asterias rubens* prefer, independently of their size, small individuals of the *Mytilus edulis*. A study, focusing on the prey-predator interaction of *Asteria rubens* and sea scallops, revealed that *Asteria rubens* appears to prefer small- to medium-sized scallops (Barbeau and Scheibling 1994a). We hypothesize that *Asteria rubens* might likewise prefer small individuals of *Mytilus edulis*, an easy prey, as they possibly have a weaker adductor muscle compared to large individuals.

Thirdly, individuals of *Asterias rubens* favor, independently of their size, large individuals of *Mytilus edulis*. A study by Dolmer (1998) showed that *Asteria rubens* prefers mussels that are about the mean size of the population itself or even larger. A likely explanation might be, that large individuals encompass a higher nutritional value and are thus predominantly selected.

Materials and Methods

The experiment in this publication was performed between the 2.10.2017 and the 12.10.17 at the Alfred-Wegener-Institute, which is part of the Wattenmeerstation Sylt, Germany.

To avoid undesirable variables and to be able to focus on the interaction between the two organisms discussed in this paper, the experiment

was conducted under laboratory conditions. The sea stars and mussels were kept separately. Furthermore, we isolated the smallest sea stars from the larger ones, to avoid potential cannibalism.

Both species were collected at different locations. Whereas the 56 *Asteria rubens* individuals were collected by using a bottom dredge during a cruise with the research trailer Mya II from a depth of approximately 5m, the 74 individuals of *Mytilus edulis* were collected during low tide from a mixed sediment mudflat (Oddewatt) immediately north of the institute. Furthermore, empty shells of *M. edulis* were collected from the beach during low tide to examine and distinguish the behaviour of the tested starfish towards live mussels and mussel shells (negative control).

We divided both, *Asteria rubens* and *Mytilus edulis* into three size categories. Of all individuals 56 Asteria rubens 24 in the size range 1,5 - 2,5 cm were categorized as small, 18 as medium (4 - 5 cm), and 14 as large (5,5 - 7,5 cm). The size categories of the 74 *Mytilus* individuals were categorized as follows: 19 small (1 - 2 cm), 30 medium (2,5 – 3,5 cm), 25 large (4,5 – 5,5 cm). The length was determined as depicted in figure 1 measuring the size of one arm from the axel to the tip of the sea stars arm, in an outstretched way. The mussel size was measured along its' ventral length.

We tested six replicates for each of the 27 mussel – starfish combinations; each combination was tested in an separate aquarium (see figure 2): Small starfish and small mussel plus negative control (small empty shell), small starfish and medium mussel plus negative control (medium empty shell), small starfish and large mussel plus negative control (large empty shell), medium starfish and small mussel plus negative control (small empty shell), medium starfish and medium mussel plus negative control (medium empty shell), medium starfish and large mussel plus negative control (large empty shell), large starfish and small mussel plus negative control (small empty shell), large starfish and medium mussel plus negative control (medium empty shell), large starfish and large mussel plus negative control (large empty shell).

Each of the tested small individuals from *A. rubens* were each placed in a small tank with the dimensions of 10x10x10 cm. The medium ranked individuals from *A. rubens* were each placed in tanks with the dimensions of 18x12x12 cm and the large individuals were each placed in tanks with the dimensions of 25x15x15 cm. The tanks were filled with fresh seawater, which was replaced before every run.

Before the start of the experiment, the organisms were allowed 15 min of acclimatisation in their respective tank. The sea stars were put in the middle of the tank and the empty shell (negative control) and the alive mussel were put in opposites sides of the tank (in the same distance to the sea star itself). The starfish were examined regarding their attacking behaviour for a time interval of 60 min. We noted whether the starfish attacked the mussel (yes/no) and how long the attack took (in min). We defined as an attack the characteristic clamp posture of the starfish around his mussel prey. The significance of the association sample – negative control was statistically tested via Fisher's exact test ($p<0,05$).

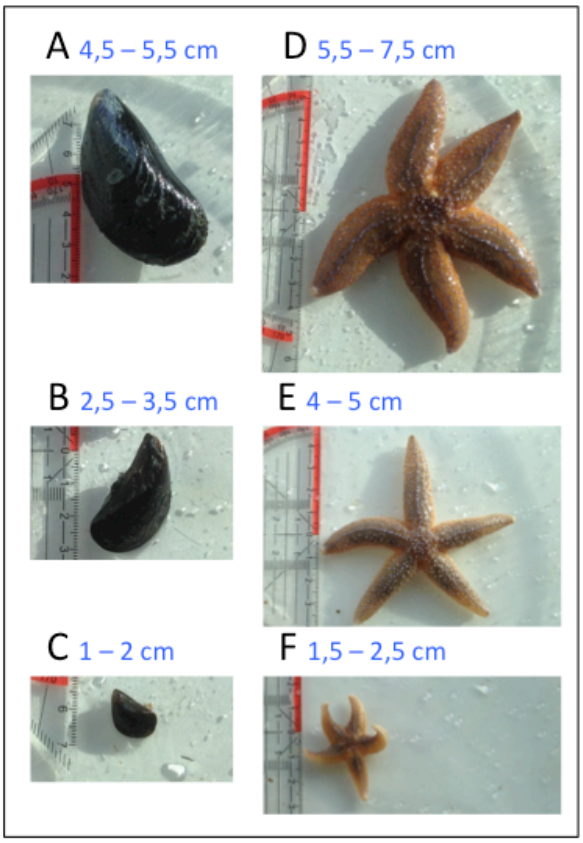

Fig. 1. Prey and predator were collected in three different sizes (small, mid-size and large). Individuals of Mytilus edulis (A large 4,5 – 5,5 cm; B mid-size 2,5 – 3,5 cm; C small 1 – 2 cm). The shells were cleaned of all attached substances like barnacles and algae before the experiment. Individuals of Asterias rubens (D large 5,5 – 7,5 cm; E mid-size 4 – 5 cm; F small 1,5 – 2,5 cm).

There are addition reasons for the bias in our study, such as the fact that the organisms where taken from their natural habitat and not observed in situ, which might lead to stress and possibly abnormal behaviour. Furthermore, the sea stars were at different levels of nutrient deprivation, because they were not fed in between trials, but might have fed shortly before getting caught.

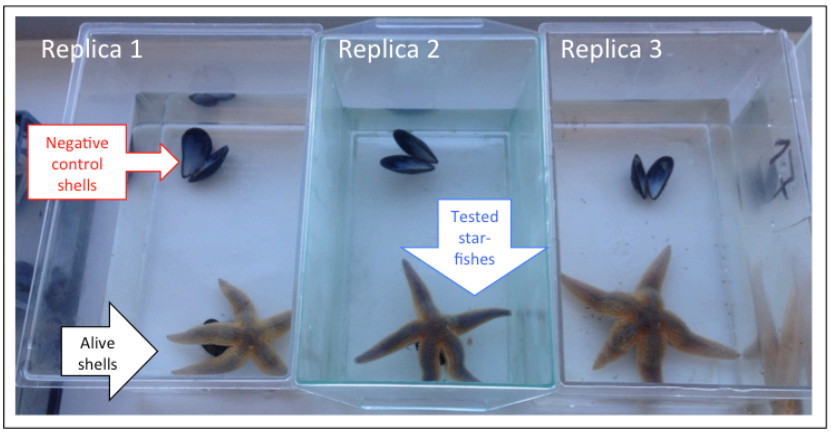

Fig. 2. The experimental set-up visualized by way of example for the combination medium sea shell medium starfish (replicates 1 to 3). At the beginning of the experiment, the shells were positioned at opposite sites of the aquarium and the starfish was placed in the middle. Possible attacks were noted in a timeframe of 60 minutes. Six replicates of each combination were tested under equal conditions.

Results

In general, we could clearly observe the characteristic feeding behavior of *Asterias rubens* in our test aquaria for all starfish sizes. When approaching an individual of *Mytilus edulis*, a quantity of starfish started an attack by clasping the mussel tightly (Figure 3A). Also, the extended stomach of the starfish became visible as depicted in figure 3B.

A majority of small-sized starfishes attacked mussels from the large category (see Figure 4). In all six replicates, the small starfish showed the typical attacking behavious towards large individuals of *M. edulis*. Only 50 % of the small individuals attacked mussels of the small size ranged and only one of the six (17 %) small-sized individuals of *A. rubens* attacked the mussels in the 2,5 to 3,5 cm size range. The mid-size starfish attacked primary large mussels (83 %), whereas mid-size mussels and small mussels were attacked in only 66 % and 33 %, respectively, of the test runs.The large starfish showed a relatively balanced attacking-behaviour: 50 % of the small and medium mussels were attacked and 33 % of the large mussels were attacked. None of the individuals of *A. rubens* show a sign of attacking behaviour towards an empty mussel shell.

Also we noted the attacking duration of the investigated individuals of *Asterias rubens* to check whether the differences in attacking probability result in diverse attacking strategies. Our results in this regard are displayed in figure 5. Small starfish showed to attack their shells for short periods, while large individuals of Asterias rubens stayed in attacking posture for the whole time interval once they caught their prey. Mid-size starfish showed to have an attack duration in-between.

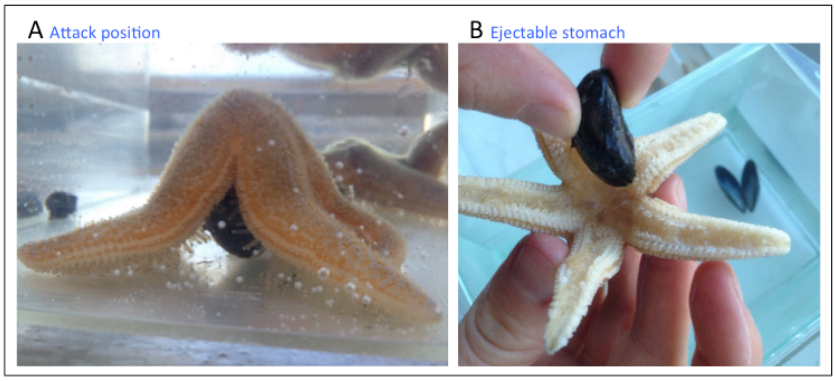

Fig. 3. When attacking, the starfish showed a characteristic behavior. A Tense clasp posture of an attacking starfish. B The extended stomach of the starfish after withdrawing his mussel prey.

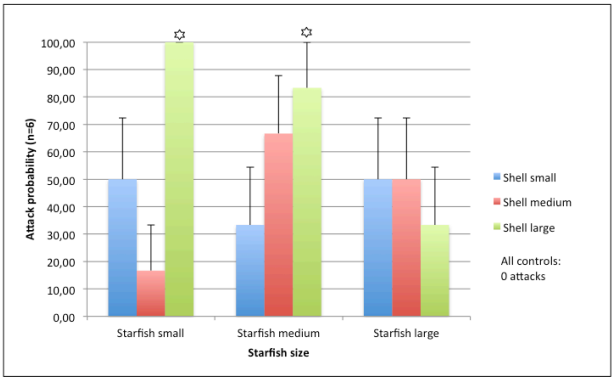

Fig. 4. The test of all starfish – sea shell combinations. The bar plots show the percentage of starfish that attacked the given mussel. Blue, red and green colour-coded bars represent small, medium or large shells, respectively.

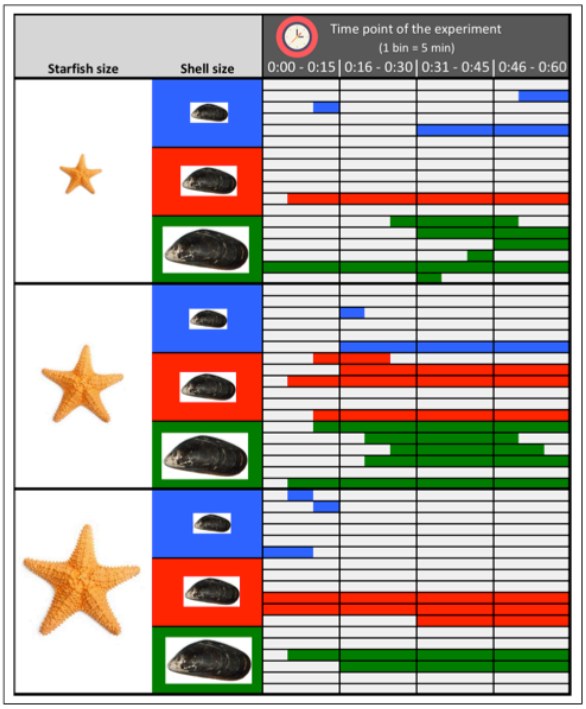

Fig. 5. The attack duration of the tested starfish – mussel combinations. In the horizontal, the time of the experiment (60 min) is displayed in bins of 5 minutes. The attack-duration of the starfish and its prey is color coded in blue (small mussel), red (mid-size mussel) and green (large mussel).

Discussion

Our first hypothesis, individuals of *Asterias rubens* select their prey according to their size, can be rejected. As depicted in figure 4, individuals of *A. rubens* from all three size categories did not, in fact, attack only mussels in their respective size category, but also smaller or larger ones.

Our second hypothesis, individuals of *Asterias rubens* prefer, independently of their size, small individuals of the *Mytilus edulis*, can be likewise rejected. None of the starfish attacked small mussels the most (figure 4).

Does this implement that our third hypothesis, individuals of *Asterias rubens* favor, independently of their size, large individuals of *Mytilus edulis*, is the most likely? Our data give corresponding hint: Small starfish (100 % attack probability on large mussels) and medium starfish (83 % attack probability on large mussels) favored large mussels. However, large starfishes slightly preferred mid-size and small mussels to large mussels.

What conclusions can be drawn from our second criteria: the duration of the attack? Figure 5 shows the results to this effect. Small starfish tend to attack mussels compared to mid-size and large starfish for briefer time periods. Mid-size starfishes showed to be the most active predators and large starfishes stayed, once they attacked, for the whole recorded time period on their prey.

Furthermore, our data indicate that mid-size starfish were the most active from our selection. This finding is in line with a study by Anger et. al (1977) that demonstrated that the average frequency of feeding is highly dependent on predator body size; it declines with growth. Correspondingly, we noted that the large starfish had a relatively low attacking probability. However, they stayed, once they attacked, fixed on their prey, whereas smaller starfish changed frequently their position on their prey to find an ideal clasp. This observation confirms the statement of Norberg & Tedengren (1995) that *Asterias* seems to be able to respond to mussel size and morphology by changing its attack strategy. If the starfish is not able to open the mussel by a short force pulse or by exhaustion, it seems to use a siege strategy and wait out its prey.

Our investigations raise several interesting questions referring to the feeding behaviour of *Asterias rubens*, for instance the implication of our assumption on the predator-prey densities in varying habitats and the general average time span of a starfish ingestion.

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